



UNIVERSITI PUTRA MALAYSIA

SUBSONIC AEROELASTIC ANALYSIS OF A THIN FLAT PLATE

DAYANG LAILA BT. ABANG HAJI ABDUL MAJID

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SUBSONIC AEROELASTIC ANALYSIS OF A THIN FLAT PLATE

By

DAYANG LAILA BT. ABANG HAJI ABDUL MAJID

**Thesis Submitted in Fulfilment of the Requirement for the Degree of
Master of Science in the Institute of Advanced Technology
Universiti Putra Malaysia**

March 2001



DEDICATION

Alhamdulillah, thanks to Allah s.w.t. upon the completion of this thesis. This thesis is specially dedicated to my beloved father, Abang Haji Abdul Majid bin Abang Taha, who during his lifetime, had continuously stressed on his children to strive for a better education. I only hope that I have inherited his great wisdom to pass on to my own children.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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Chairman: Associate Professor ShahNor Basri, Ph.D., PEng.

Institute of Advanced Technology

The interaction between an aircraft structure and the airflow surrounding it has been known to severely affect the stability, performance and manoeuvrability of the aircraft. These interactions form the heart of aeroelasticity, a field that comprises all types of aeroelastic phenomena. In this work, a parametric aeroelastic analysis of a thin flat plate clamped at the leading edge and exposed to subsonic airflow was conducted. The aeroelastic effects predicted to occur was flutter, a type of self-excited oscillation.

The analysis was simulated using ZAERO, a panel code aeroelastic program, which requires free vibration input, obtained using MSC-NASTRAN, a finite element code. The flutter equation was obtained using Newton's Law of Motion to model the plate while the airflow was modeled using the Small Disturbance Unsteady Aerodynamic Theory. Free vibration results and flutter results obtained were validated against published works found in reference [8, 60 and 61].

The important parameters studied were the aspect ratio and the mass ratio of the plate. The effect of the number of free vibration modes employed in the analysis was also tested. From the results, it was shown that the flutter velocity decreased as the mass ratio and aspect ratio were increased. The flutter frequency also decreased with higher mass ratio and at large aspect ratio. The use of a higher number of modes in the flutter analysis was found to increase the accuracy of the flutter.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

ANALISIS AEROELASTIK SUBSONIK UNTUK SEBUAH PLAT YANG NIPIS DAN RATA

Oleh

DAYANG LAILA BT. ABANG HAJI ABDUL MAJID

Mac 2001

Pengerusi: Profesor Madya ShahNor Basri, Ph.D., PEng.

Institut Teknologi Maju

Interaksi antara struktur pesawat dan udara sekelilingnya telah diketahui boleh mempengaruhi kestabilan, prestasi dan olahgerak pesawat tersebut. Interaksi inilah yang merupakan nadi keaeroelastikan, suatu bidang yang merangkumi kesemua jenis fenomena aeroelastik. Dalam kerja ini, analisis parametrik aeroelastik untuk suatu plat nipis dan rata yang diikat pada hujung mendahulu dan terdedah kepada aliran subsonik telah dijalankan. Kesan aeroelastik yang dijangka berlaku adalah 'flutter', iaitu sejenis getaran teruja sendiri.

Simulasi ini telah dijalankan menggunakan ZAERO, perisian aeroelastik berasaskan kod panel, yang memerlukan input getaran bebas diperolehi menggunakan MSC-NASTRAN, sebuah kod elemen terhingga. Persamaan untuk 'flutter' diperolehi dengan menggunakan teori Gerakan Newton untuk model plat dan aliran udara dimodel dengan menggunakan teori Aerodinamik Gangguan Kecil dan Tak Mantap. Keputusan getaran

bebas dan 'flutter' diperolehi dan disahkan oleh hasil-hasil kerja yang telah diterbitkan dalam rujukan [8, 60 dan 61].

Parameter-parameter penting yang dikaji adalah nisbah aspek dan nisbah jisim plat tersebut. Kesan daripada bilangan mod getaran bebas yang digunakan dalam analisis juga dikaji. Daripada keputusan, didapati halaju 'flutter' berkurang apabila nisbah aspek dan nisbah jisim bertambah. Frekuensi 'flutter' juga didapati menurun dengan pertambahan nisbah aspek dan nisbah jisim. Penggunaan bilangan mod yang tinggi dalam analisis 'flutter' didapati telah memperbaiki ketepatan 'flutter'.

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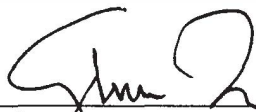
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CHONG FAI KAIT, Ph.D
Institute of Advanced Technology
Universiti Putra Malaysia
(Chairman)

SHAHNOR BASRI, Ph.D
Associate Professor,
Institute of Advanced Technology
Universiti Putra Malaysia
(Member)

WAQAR ASRAR, Ph.D
Associate Professor,
Faculty of Engineering
Universiti Putra Malaysia
(Member)


FAIZAL MUSTAPHA
Faculty of Engineering
Universiti Putra Malaysia
(Member)



MOHD. GHAZALI MOHAYIDIN, Ph.D
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia

Date: 04 APR 2001

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

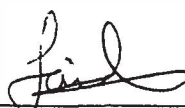


MOHD. CHAZALI MOHAYIDIN, Ph.D
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia.

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



(DAYANG LAILA BT. ABANG HAJI ABDUL MAJID)

Date: 4 April, 2001

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Ratio = 0.1

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Ratio = 0.3

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Ratio = 0.5

LIST OF ABBREVIATIONS

a_{∞}	speed of sound
b	width of plate
g	aerodynamic damping
g_s	structural damping
h_x, h_y, h_z	interpolated deformation at aerodynamic boxes in x, y, z direction
h_m	plate's thickness
k	reduced frequency
l	length of plate
m	mass
\bar{n}	unit surface normal
n_x, n_y, n_z	components of \bar{n} in the x, y and z direction
p	pressure
p_l	dummy integration variable
p_{ref}	reference pressure
q_{∞}	freestream dynamic pressure
q	Lanczos vector
t	time
u, v, w	velocity component in the x, y and z direction
$\hat{u}, \hat{v}, \hat{w}$	perturbation velocity in the x, y and z direction
$\hat{u}_0, \hat{v}_0, \hat{w}_0$	steady perturbation velocity in the x, y and z direction
x, y, z	global coordinates

∇	gradient operator
α, β	scalar coefficient of $[T]$ matrix
ε	elementary source solution
γ	specific heat ratio
ϕ	velocity potential
$\hat{\phi}$	perturbation velocity potential
$\bar{\phi}$	modified potential
ρ_a	air density
ρ_{ai}	dummy integration variable
ρ_m	mass density
σ	source singularity
Φ	doublet singularity
Ω	complex eigen-value
τ	compressible reduced frequency
ω	natural frequency
ω_f	flutter frequency
$\bar{\omega}$	non-dimensional frequency
λ	eigenvalue
μ	eigenvalue of $[T]$ matrix
ξ, η, ζ	local coordinates
$[\varphi]$	modal matrix
A	fluid element's surface

dA	surface elemental area
C_p	pressure coefficient
D	flexural rigidity
E	Young's modulus
$[\bar{C}]$	damping matrix
$\{F(t)\}$	total aerodynamic force
$\{F_d(\chi)\}$	aerodynamic force induced by structural deformation
$\{F_e(t)\}$	external aerodynamic force
$\{F_b\}$	downwash function on arbitrary bodies
$\{F_w\}$	downwash function on flat plate type of lifting surface
$[G]$	spline matrix
$\{h\}$	interpolated deformation at aerodynamic boxes
$[H^e]$	strain-displacement matrix
K_{sub}	Subsonic Kernel
K_{super}	Supersonic Kernel
$[K]$	generalized stiffness matrix
$[\bar{K}]$	stiffness matrix
L	reference length of plate, $b/2$
$[M]$	generalized mass matrix
$[\bar{M}]$	mass matrix
M_∞	freestream Mach number
$[N]$	shape function
N_x, N_y	number of nodes in x and y direction

R_x, R_y, R_z	rotational degree-of-freedom at x, y, z direction
$Q(ik)$	generalized aerodynamic force
$\{\bar{q}\}$	generalized coordinates
$\{\bar{z}\}$	eigen-vector of $[T]$ matrix
S	surface of plate
T_x, T_y, T_z	translational degree-of-freedom at x, y, z direction
\bar{U}	fluid velocity vector
U_f	flutter velocity
U_∞	freestream velocity
V	fluid element's volume
W	wake surface
\bar{Z}	modal structural damping
$\{\chi(t)\}$	displacement vector
$\{\ddot{\chi}(t)\}$	acceleration vector
$\{\hat{\chi}\}$	displacement amplitude vector
$[AIC]$	aerodynamic influence coefficient matrix
$\frac{\rho_a l}{\rho_m h_m}$	mass ratio
$B = \sqrt{ 1 - M_\infty^2 }$	
$\tilde{A} = \left(\frac{U^2}{L^2}\right)M$	
$\tilde{B} = 2ik\left(\frac{U}{L}\right)^2 M - \frac{1}{2}\rho U^2 Q'(ik) + \left(\frac{U}{L}\right)Z$	

$$\tilde{\mathbf{C}} = -k^2 \left(\frac{U}{L} \right)^2 \mathbf{M} + \overline{\mathbf{K}} - \frac{1}{2} \rho U^2 \mathbf{Q}(ik) + ik \left(\frac{U}{L} \right) \mathbf{Z}$$

where \mathbf{Z} is a modal structural damping matrix and $\mathbf{Q}'(ik) = \frac{\partial \mathbf{Q}(ik)}{\partial (ik)}$.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Modern aircraft structures are extremely flexible and therefore tend to deform when exposed to airflow [1]. This usually involves the interaction of inertial, elastic and aerodynamic forces, which consequently may result in static and dynamic deformations and instabilities. Aeroelasticity deals with the behaviour of an elastic body or vehicle in an air stream, whereby there is significant reciprocal interaction or feedback between deformation and flow [2]. These aeroelastically-induced deformations may have severe consequences on the stability, performance and manoeuvrability of an aircraft. However, dynamic instabilities often provide more cause for concern than static instabilities, whereby the final consequence usually leads to failure.

Because of this practical consequence, understanding of the aeroelastic behaviour is critical, which necessitates the need for reliable prediction tools that can model all the important characteristics of the interaction. As an interdisciplinary field, aeroelasticity requires the coupling of the aerodynamic and structural responses. Computationally, this will involve coupling of computational disciplines such as Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD), which are generally referred to as Computational Aeroelasticity (CA) [3]. From an engineering viewpoint, the major aim in computational aeroelasticity is therefore to describe the influence of structural deformations on the aerodynamic load and vice versa.